

A Model-based Fully Automatic Algorithm for Brain Extraction on 3D MRI Scans

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Introduction

A model-based fully automatic algorithm is presented for brain extraction on 3D MRI scans. Given a 3D structural MRI of the head, the objective of this algorithm is to classify each voxel within the image volume as either brain or non-brain. Brain extraction, as a preliminary step, often improves the results of inter-subject non-linear image registrations. It is also a very useful first step in automatic brain tissue classification algorithms. We have compared the algorithm presented in this paper with several previously published programs and have found it to be superior to those techniques. An implementation of this algorithm is freely available online at: www.nitrc.org/projects/art.

Methods

The algorithm presented in this paper is model-based. This involves a training phase that is performed once according to the following procedure. Let us assume that we have available a set of M model MRI volumes on which the brain has been manually extracted, as well as a template MRI volume. (1) a probabilistic brain map p with the same matrix and voxel dimensions as the template volume is considered, initially having zero voxel values everywhere; (2) each model volume i is registered to the template volume by determining a linear affine transformation T_i ; (3) the inverse affine transformation T_i^{-1} is applied to every voxel v on the template volume; (4) if the image of voxel v under the inverse affine transform T_i^{-1} falls on a brain voxel in the model volume i , the corresponding voxel v on the probabilistic map is incremented by 1; (5) finally all voxel values in the probabilistic map are divided by M , so the voxel values in p range from zero to one.

The probabilistic map obtained using above method is applied in brain extraction of a test volume by the following steps: (1) the test volume is registered to the template by determining a linear affine transformation T_t ; (2) the inverse transformation T_t^{-1} is applied to the probabilistic map and the resulting map is re-sampled to the same matrix and voxel dimensions as the test volume; (3) on the test image, the background voxels outside the head are separated from the foreground voxels using a simple thresholding operation where the threshold is determined automatically using Otsu's method; (4) using the re-sliced probabilistic map in the test volume space and the foreground voxel intensities, two empirical probability functions $P(I|b)$ and $P(I|\bar{b})$ are determined, which represent the conditional probabilities of a voxel having an intensity I given it is a brain or non-brain voxel; (5) the foreground voxel are classified as brain or non-brain according to their posterior probabilities: $P(I|b)P(b) \geq P(I|\bar{b})P(\bar{b})$, where the prior probability $P(b)$ ($= 1 - P(\bar{b})$) is the value of the re-sliced probabilistic map at the voxel under consideration; (6) if a voxel is classified as non-brain, its corresponding value on the re-sliced probabilistic map is set to zero; (7) steps (4)-(6) are repeated until the foreground voxel classification does not change; (8) the expectation-maximization (EM) algorithm is applied to the histogram of the foreground voxel values that have been classified (so far) as the brain to classify these voxels into two groups: CSF and brain parenchyma; (9) a 3D connected component filter is applied to the parenchyma voxels only, whereby the largest connected component is retained and all others are classified as non-brain; and (10) the final classification of the brain voxels is taken to be the CSF voxels in step (8) plus the parenchyma voxel in step (9) corresponding to the largest connected component.

Experiments and Results

To assess the performance of the algorithm, 130 3D T₁-weighted structural MRI scans, comprising 50 healthy subjects, 50 patients with chronic schizophrenia, and 30 subjects with a history substance abuse were utilized. All subjects were participants in research projects approved by the local Institutional Review Board and provided written informed consent. The MRI scans were performed using a 1.5 T Siemens Vision system (Siemens AG, Erlangen, Germany). High-resolution sagittal 3D T₁-weighted volumes were acquired from each subject using a magnetization-prepared rapid acquisition gradient echo (MPRAGE) sequence with the following parameters: TR=11.6 ms, TE=4.9 ms, flip angle=8°, FOV=256×256×190 mm³, matrix size=256×256×190, 1 mm³ isotropic voxel size.

For training purposes, 80 3D T₁-weighted structural MRI scans were manually skull-stripped. These images were used to determine the probabilistic map described above. Using this map, the brain extraction method was applied to the remaining 50 additional scans. Three other programs (FSL's BET, FreeSurfer, and AFNI) were also applied to the same 50 images for comparison. The results were visually inspected for two types of misclassifications: (a) when non-brain regions are left after brain stripping; and (b) when parts of the brain are incorrectly removed. Our algorithm resulted in the fewest number of errors, followed by FreeSurfer, AFNI, and BET.

The probabilistic model developed above using 80 scans is distributed along with the program. Additional studies are required to determine how this model will perform for brain extraction on scans acquired on other systems, pulse sequences, and subject populations. Further studies are also required to determine the minimum number of model scans necessary to obtain satisfactory results using the above scheme, as is a more quantitative evaluation of the method.